Tribological analysis of formation and rupture of oxide films in an electrical sliding contact copper-steel

Choubeila Boubechou*[1], Ali Bouchoucha[2], Hamid Zaidi[3]

[1]Faculté de Technologie, Département de Génie Mécanique, Université 20 Août 1955, Skikda 21000, Algérie.
[2]Laboratoire de Mécanique, Faculté des Sciences de technologie, Département de Génie Mécanique, Université Constantine1 25000, Algérie.
[3]Laboratoire LMS (UMR-6610-CNRS), SP2MI, Téléport 2, Boulevard Marie et Pierre Curie, Université de Poitiers, BP 30179, 86962 Futuroscope Chasseneuil Cedex, France.

*[1]choubeila_boubechou@yahoo.fr; [2]bouchoucha_ali1@yahoo.fr; [3]hamid-zaidi@univ-poitier.fr

Received 31 March 2014; Accepted 9 June 2014; Published 8 July 2014

Abstract

On electrical rail line, the copper-stainless steel couple is used to transfer electric current. During sliding oxidation occurs; then the surface is covered with a thin film mixture of oxides and transferred elements. Its formation is due to the conditions of friction at the contact level. The thickness of this film increases with a time until it breaks where its critical depth is reached. The growth speed of oxide films is a function of mechanical and/or electrical parameters and quantity of oxygen present at the contact. A decrease or an absence of oxygen affects friction and wear. The aim of this paper is then to present experimental study of friction and wear behavior of electrical sliding contact and their variations by the presence or no of electrical field. We will discuss the effect of oxygen on the nature of oxide films generated at the interface and the tribological behavior of the couple.

Keywords

Friction; Wear; Oxide Film; Electrical Current; Copper Stainless-steel Couple; Oxygen; Air and Argon

Introduction

On electrified rail line, necessary energy for the traction of vehicles on rail is transferred by sliding contact copper-stainless steel. During the functioning, the couple is submitted to severe conditions, in more of electrical and mechanical parameters. The aim of the present study is to describe the metallic transfer and explain the effects of electrical current on the transferred elements and their consequences on friction and wear behaviors. We will present the effect of oxygen with and without current on the surface film oxides growth. To reveal these effects, friction and wear behaviors of the couple are studied under various environments: oxygen, air and argon. The results are compared and instantaneous evolutions of sliding surface is observed and analyzed.

Experimental Device

Experiments were carried out with a pin-on-disc system tribometer which has been modified in a tensed wire-on-disc and described elsewhere. The disc has been replaced by 16 sectors on one side wheel and the pin by a U shape frame on which a copper wire is stretched. The tension force of the wire T is measured by stresses gauges which are glued on one arm. The normal load is vertically applied with a weight P. The horizontal wheel is driven by an electrical motor with variable speed V.

Materials

Chemical Constitution Of Materials

	C	Cr	Ni	Cu
304L	0.03	18	10	/
Cu	/	/	/	99.98

Results

Friction Behavior

Under oxygen and humid air, the friction behavior is the same than this in air $\mu = f(V)$. For $0 < V < 1.2$ m/s, $\mu = f(V)$ increase with sliding speed and reaches $\mu = 0.6$. Above 1.2 m/s, μ decreases and stabilizes at $\mu = 0.5$

when V = 5m/s. However, in argon, friction coefficient is higher than those obtained in other atmosphere. It presents a maximum at the same speed. At V = 7.2 m/s μ reaches the value of μ = 0.57 (Fig. 2).

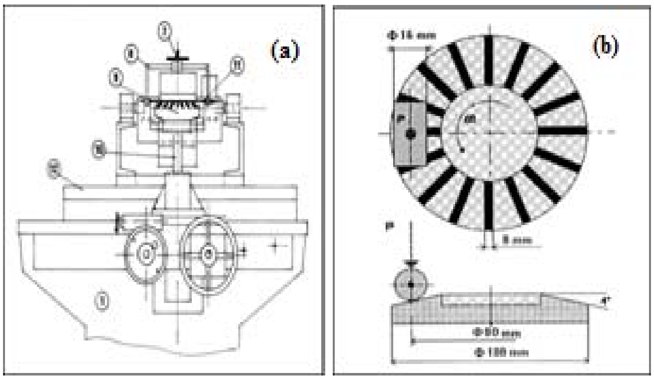

FIG. 1 WIRE-DISC TRIBOMETER

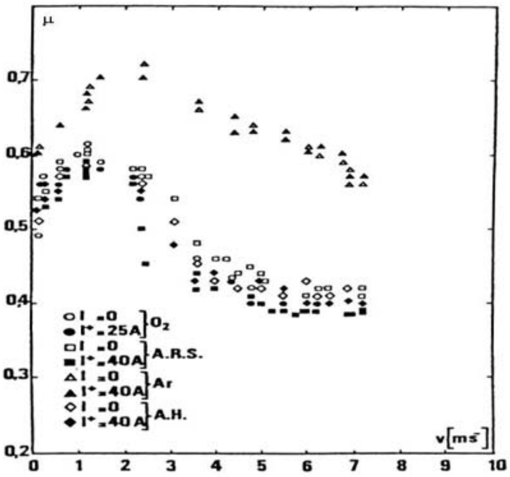

FIG. 2 VARIATION OF FRICTION COEFFICIENT VERSUS SLIDING SPEED IN DIFFERENT ATMOSPHERES (T = 360N; P = 10 N; tf = 3600s)

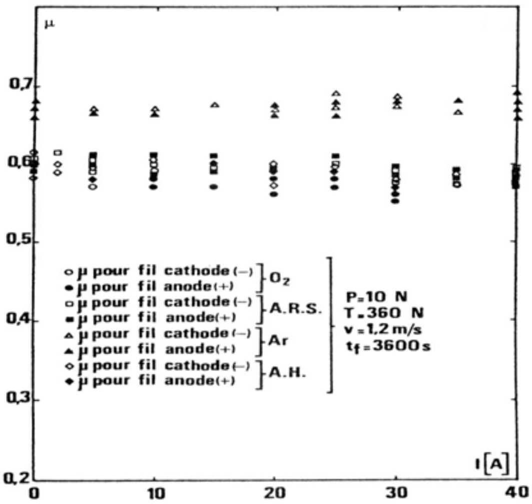

FIG. 3 VARIATION OF FRICTION COEFFICIENT VERSUS ELECTRICAL CURRENT IN DIFFERENT ATMOSPHERES

(T = 360N; V = 1.2 m/s; P = 10 N; tf = 3600s)

The study of the electrical current influence, under oxygen atmosphere, shows that:

- Above 30A electrical arcing are created and the sliding surface is damaged (Fig.3).

- When we increase the electrical current from 0 to 30A, the friction coefficient remains constant in argon and in oxygen atmosphere (Fig. 3).

Wear Behavior

Figure 4 shows the influence of normal load on wear of copper wire under oxygen, ambient atmosphere and under argon. Wear rate increases with normal load. It is high under oxygen, low under ambient atmosphere and very under argon (Fig. 4).

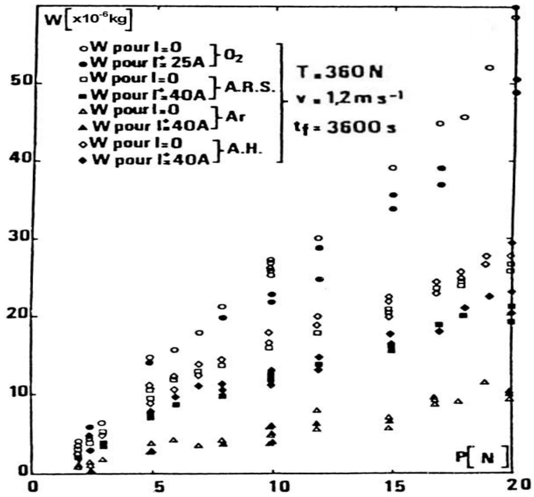

FIG. 5 WEAR VARIATION WITH SLIDING SPEED IN DIFFERENT ATMOSPHERES (T = 360N; P = 10 N; tf = 3600s)

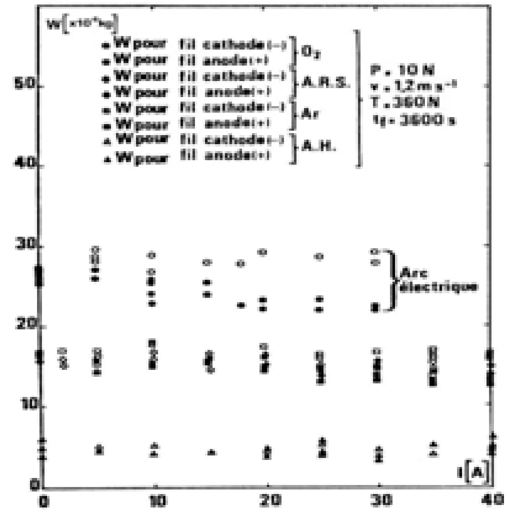

FIG. 6 WEAR VARIATION VERSUS ELECTRICAL CURRENT IN DIFFERENT ATMOSPHERES

(T = 360N; V = 1.2 m/s; P = 10 N; tf = 3600s)

Electrical current intensity and polarity have no significant effect under argon. On another hand in oxygen and air, the wear depends on electrical intensity and on polarity as we will discuss it in discussion. The wear mode changes from oxidation to

abrasive mode with current intensity.

Discussion

Normal Load

Under air or oxygen, the friction coefficient μ is the same, but under argon it is high and the transferred copper quantity on the disc is important. Above 15N of normal load, we have noted that the electric contact resistance is low ($1.5.10^{-3}$ Ω). Wear particles are essentially copper metal (Fig.7). Friction coefficient remains constants and tangential force increases linearly with normal load. That shows the real contact surface increase and oxide film removal with increase of normal load. Wear rate depends on the environment. The amount of oxygen in the environment has a major effect on the wear (Fig. 4). Under oxygen, the wear of wire W varies by factor of two with respect to that in air. On the contrary, under pure argon this wear is devised by factor of three with respect to that in air.

Sliding Speed

At low speed (0.2 < V < 1.2 m/s), friction coefficient and wear rate are high in (Fig. 2). The cycle time between asperities is enough to increase rapidly the contact section by fluage. The section increase in sliding direction is elliptic. Oxidation is low.

At low speed (1.2 < V < 5 m/s), contact temperature and then oxidation increases. A compact layer is formed on wire. The film becomes ductile under high contact temperature induced by the high electric contact resistance. It lubricates the contact and protects the damage surface. Tylecotte has shown that the ductility of the copper oxide film depends essentially on the testing temperature, rather than on the film thickness or the actual composition (CuO, Cu_2O), it has been shown that copper oxide can acts as a lubricant on copper at high temperature.

At high speed (5 < V < 8m/s), the temperature increases further, the oxide layer disintegrated, the strength of the substrate is lower, the contact break and the substrate softens. Friction coefficient remains constant at 0.41, but the wear increases. The sliding surface reveals an abrasive wear mode. The sliding surface is deeply deformed. Some colored zones characteristic of thermal affected domain are observed. However, under argon, friction coefficient increases and decreases above V=2.5m/s is probably the critical value where the copper reaches it's soften temperature (120°C). Then total wear increases.

Influence Of Electrical Current

Microanalysis X-ray identifies oxide layer structure formed on copper wire. The presence of CuO can be justified by the high temperature reached in contact asperities. The fluctuations amplitude of μ = f(t) increase with electrical current intensity. Damage of disc sliding surface increases too.

- 0<I<20 A: The observations under an electronic microscope reveal that oxide layer is very adherent to the substrate, not detachable from copper wire. This layer is dense, regular and fits the irregularities of the surface. It lubricates the sliding contact.

- The increase of electrical intensity 20A< I <40A activates the oxidation process at the interface: the transferred elements iron and chrome oxidize and the oxidation of the disc track leads to the rapid formation of hard oxides Fe_2O_3 and Cr_2O_3 released as grains at the interface (Figs .7 and 8).

Therefore, the influence of electrical current and its polarity has been demonstrated according to the Cabrera and Mott theory. We have proposed an equivalent electric field effect in sliding contact temperature. The equilibrium wire temperature varies between 30 and 350°C. The values calculated show that the temperature at interface during the sliding movement can rise up to 600°C.

The calculations show that the wear mode in this sliding contact between copper and chrome steel is not the same for different current directions. When the copper wire is the anode, the wear mode is essentially the oxidation type, but when the wire is cathode the wear is the abrasive one.

In these conditions, when the copper is the anode, the copper oxidation speed is higher while the steel oxidation speed is lower. In this case, we observe experimentally that the copper wear is low. When the copper is the cathode, the opposite occurs. This is due to the fact that a high steel oxidation leads to the rapid formation of hard iron and chrome oxide released as grains at the sliding interface, abrading strongly the contact face wire. Our observations under the microscope confirm this abrading action.

In addition, the asperities are the sites for the oxidation (at oxidation temperature). Since oxidation occurs by diffusion of oxygen ions inwards and sometimes by metal ions outwards, one would expect

the plateau to grow in height from the interface between the oxide and the metal between beneath each asperity contact. In the course of many passes, one would find that the increases in height were speared over the whole contact area of the plateau. When the plateau reaches a critical oxide film thickness, the film becomes unstable and breaks up to form flakes and eventually wear debris.

The speed with which loose debris were produced seems to be governed by the degree of oxidation. The oxide film is very thin and essentially follows the surface topography of the disc. The transfer from the wire to the disc increases with increasing sliding speed applied load P and electric current intensity I.

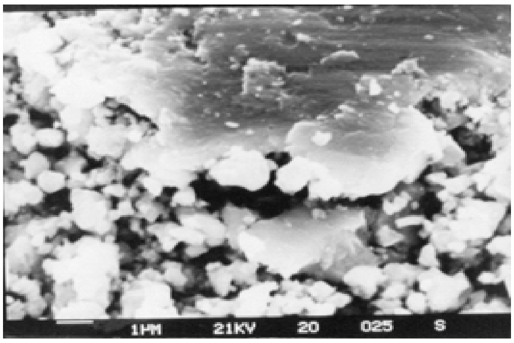

FIG . 7 SEM OF WEAR PARTICLES
(P = 10N; T = 360 N; I+ = 40A; V = 1.2 m/s; tf = 3600 s).

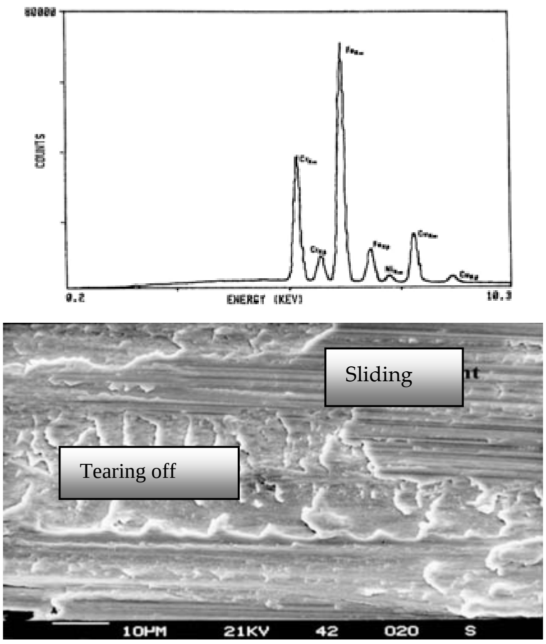

FIG. 8 EDX MICROANALYSIS (A) AND SEM (B) OF WORN WIRE FACE UNDER OXYGEN
(P = 10N; T = 360 N; I+ = 40A; V = 1.2 m/s tf = 3600 s).

Under argon, the transfer of copper on the disc leads to a contact copper on copper. However, under an oxidizing medium with or without electrical current, one can distinguish:

- If I = 0: the transfer of copper is followed by oxidation. The predominant oxide is CuO. Then the friction coefficient versus time is stable and the wear is the oxidation type.

- If I≠ 0: the degree of oxidation increase. The transferred elements oxide and the formation of hard oxides occur particularity Cr_2O_3 and Fe_2O_3. The evolution of the friction coefficient is instable. In addition to oxidation wear, the abrasion wear manifests.

Conclusions

This study reveals the effect of oxide layer on friction and wear of electrical sliding contact copper-steel. The transfer and oxidation occur during friction. These two mechanisms are cycle way favored and disadvantaged by normal load, the velocity and/or the electrical intensity. This effect depends on the environment around the tribocontact. The friction coefficient remained almost the same when rubbing occurs under air or oxygen. But it increases under argon. However, the wear increases under oxygen and diminishes in argon with respect in air. Wear process of sliding electrical contact is modified continuously by its mechanical parameters according to the electrical current intensity. Surfaces can be damaged by abrasive wear, by oxidation or an arc electrical at the contact.

REFERENCES

Adamou A.S., “Comportement tribologique et réactivité de l’alliage 718 en atmosphère contrôlée et à haute température“. Thèse de doctorat INPT, Spécialité : science et génie des matériaux, Toulouse, France, 2005.

Ali, Bouchoucha. “Etude du comportement en frottement et usure des contacts électriques glissants cuivre-acier et cuivre-graphite“. thèse de doctorat INPL, Nancy, France 1997.

Bonchoucha A. et al. “Influence of electric fields on the tribological behavior of electrodynamical copper/ steel contacts“. Wear 203-204, 1997, 434-441.

Bucca G. and Collina A. “A procedure for the wear prediction of collector strip and contact wire in pantograph–catenary system“. Wear 266, 2009, 46-59.

Cabrera and Mott N F., “Theory of Metal Oxidation“. North Holland Publishing Company, Amsterdam 1976. Signatur an der Bibliothek der Uni Graz: I 466591.

Chiou Y.C. and al. "Formation mechanism of electrical damage on sliding contacts for steel pair". Wear 266, 2009, 110–118.

Diehl M. G., "Wear of electrical contacts". Vol. 1 1957/58, Wear, References p. 376.

Hai He D. and al. "A sliding wear tester for overhead wires and current collectors in light rail systems", Wear 239, 2000, 10–20.

Laraqi N. and al. "Temperature and division of heat in a pin-on-disc frictional device-exact analytical solution". Wear, 2008, 08.016.

Park W. and al. "The influence of current load on fretting of electrical contacts". Tribology International, 2008, 09.004L.